CLAIMS

That which is claimed is:

1. In a robotic arm structure providing θ-, R- and Z-motion which includes at least two links, each having a proximalmost end portion and a distalmost end portion, with the θ motion being about a primary axis at the proximal end portion of a proximalmost of the links, R motion proceeding radially from the primary axis whereby the distal end portion of a distalmost of the links can be moved radially in a straight line, an end effector having an end effector portion thereof pivotally mounted for rotation relative to the distal end portion of the distalmost link about an end effector axis which is parallel to the primary axis, the arm structure being controlled by electronic computer means controlling the θ-, R- and Z- motions, sensor means for sensing the R, θ- and Z- motions and for creating electronic signals representative thereof and signal transmission means for delivering the electronic signals to the computer means, the improvement comprising:

Sub. B1

motor means connected to rotate the end effector about the end effector axis and to thereby provide a yaw (Y) motion;

wherein the sensor means further includes means for sensing the Y-motion and creating an electronic signal representative thereof;

wherein the signal transmission means further includes means for delivering the electronic signal representative of the Y-motion to the

Sub. B1 cont'd

computer means; and

wherein the electronic computer means further includes means for monitoring and controlling the Y-motion such that the end effector can be moved in a straight line which is not restricted to the radial direction.

2. The robotic arm structure of claim 1 wherein the electronic computer means further includes means for monitoring and controlling the θ-, R-, Z- and Y-motions such that the distal end portion of the distalmost of the links can be moved in arbitrary continuous paths, including multisegment smooh trajectories and straight lines, which are not restricted to a radial direction while maintaining a prescribed orientation of the end effector.

3. A workpiece processing system which includes a set of cassettes arranged in a substantially straight line loaded with workpieces in combination with the arm structure of claim 1.

4. A workpiece processing system which includes a conveyor belt which transports cassettes loaded with workpieces along a path such that the cassettes are not all radially accessible to the end effector in combination with the arm structure of claim 1.

Sub. B2

5. A plurality of arm structures in accordance with claim 1, each having one or more work stations within its reach, the arm structures being position sufficiently close together such that after a workpiece has been transported to one of the work stations within reach of a first of the arms and processed, it is then

transported by the first of the arms to a transfer station which is also within the reach of the second of the arms for processing at work stations within the reach of the second arm.

6. A sensor array located in a position such that a workpiece being transported by an arm as set forth in claim 1 passes over the sensor array whereat any deviation in alignment of the workpiece, if present, is determined and an electronic error signal is generated and communicated to the electronic computer means which controls the arm to make the appropriate R-, Θ- and Y- corrections to properly align the workpiece.

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7. A robotic arm system as set forth in claim 1, further characterized in including:

at least one additional end effector pivotally mounted for rotation relative to the distal end portion of the distalmost link about the end effector axis;

additional motor means connected to rotate each additional end effector about the end effector axis and to thereby provide a yaw (Y) motion;

wherein the sensor means further includes means for sensing the Y-motion of the additional end effector and creating an electronic signal representative thereof;

wherein the signal transmission means further includes means for delivering the electronic signal representative of the Y-motion of the

additional end effector to the computer means; and

Sub. B2 cont'd.

wherein the electronic computer means further includes means for monitoring and controlling the Y-motion of the additional end effector such that the additional end effector can be moved in a straight line which is not restricted to the radial direction.

8. A method for controlling a robotic arm structure utilizing electronic computer means, the arm structure having a radial drive shaft and a rotary drive shaft respectively providing R- and θ- motion and having an end effector drive shaft providing Y (yaw) motion, each drive shaft being driven by a respective motor, the arm structure having n longitudinally extending links, each link having respective proximal and distal end portions, n being 2 or a larger integer, and an end effector mounted at a distal end portion of an outermost of the links, comprising the steps of:

repeatedly measuring the rotational positions of the radial drive shaft, the rotary drive shaft and the end effector drive shaft;

generating electronic signals representative of the rotational positions;

communicating the electronic signals representative of the rotational positions to the electronic computer means;

utilizing the electronic computer means to compute the locus of the end effector from the electronic signals representative of the rotational positions

of the drive shafts, and to control the drive motors to move and position the end effector in any desired location within its reach.

9. The method of claim 8 wherein the step of utilizing comprises the substeps of:

continuously generating the desired position, orientation, velocity, acceleration and jerks of the end effector;

continuously measuring the motor positions;

solving a direct kinematic problem at position level by calculating the position and the orientation of the end effector, and an end effector tracking error;

calculating the current end effector path;

generating a velocity profile of the end effector;

calculating an end effector velocity vector;

solving an inverse ~~of~~ the kinematic problem at velocity level;

transfoming joint velocities into motor velocities; and

communicating the motor velocities to the motors.

10. In an arm structure providing θ-, R- and Z-motion which includes at least two links, each having a proximalmost end portion and a distalmost end portion, with the θ motion being about a primary axis at the proximal end portion of a proximalmost of the links, R motion proceeding radially from the primary axis whereby the distal end portion of a distalmost of the links can be moved in arbitrary continuous paths including multisegment smooth trajectories and straight lines and an end effector having an end effector portion thereof pivotally mounted for rotation relative to the distal end portion of the distalmost link about

an end effector axis which is parallel to the primary axis, the improvement comprising:

a motor mounted to a respective one of the distalmost link and the end effector, the motor being connected to drive relative rotation about the end effector axis between the distal end portion of the distalmost link and the end effector portion and to thereby provide a yaw (Y) motion;

sensor means for sensing the R, Θ, Z and Y motions and for creating electronic signals representative thereof;

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signal transmission means for delivering the electronic signals to the computer means;

electronic computer means for monitoring and controlling the R, Θ, Z and Y motions, the electronic computer means including means for monitoring and controlling the Y-motion such that the end effector can be moved in a straight line which is not restricted to the radial direction.

11. A workpiece processing system which includes a set of cassettes arranged in a substantially straight line loaded with workpieces in combination with the arm structure of claim 10.

12. A wafer processing system which includes a conveyor belt which transports cassettes loaded with wafers or other objects along a substantially straight line path used in combination with the arm structure of claim 10.

13. A plurality of arm structures in accordance with claim 10, each having one or more work stations within its reach, the arm structures being positioned sufficiently close together such that after a wafer has been transported to the work station(s) within reach of a first of the arms and processed, it is then transported by the first of the arms to a transfer station which is also within the reach of the second of the arms for processing at work stations within the reach of the second arm.

14. A sensor array located in a position such that an object being transported by an arm as set forth in claim 12 passes over the sensor array whereat any deviation in alignment of the object, if present, is determined, and an electronic error signal is generated and communicated to the electronic computer means which controls the arm to make the appropriate R, θ and Y corrections to properly align the object.

15. A robotic arm mechanism adapted to manipulate workpieces which provides R, θ and Y (yaw) motion, comprising:

Sub. B3

two pairs of linkages, each linkage having a proximal link having proximal and distal end portions and a distal link having proximal and distal end portions, the distal end portion of the distal link of each of the pairs of linkages being pivotally mounted at a distal axis to one another, the distal end portion of each proximal link being pivotally mounted to the proximal end portion of the corresponding distal link at a respective elbow axis, the proximal end portion of each proximal link being pivotally mounted at a

respective shoulder axis to a relatively static support and in spaced apart relation to one another;

an end effector mounted at the distal end portion of the distal links for pivotal motion about the distal axis, all of the pivotal axes being parallel to one another and extending in a first direction, the links and the end effector being spaced from one another along the direction of the axes such that the links can be moved orthogonally to the first direction in a volume extending along the first direction without obstruction from one another;

Sub. B3 Cont'd.

a yaw motor connected to drive relative rotation of the end effector about the distal axis;

an elbow motor connected to drive relative rotation between the proximal end portion of a respective one of the distal links and the distal end portion of the corresponding proximal link; and

a shoulder motor connected to drive rotation of the proximal end portion of one of the proximal links relative to the static structure.

~~16. A robotic arm mechanism as set forth in claim 15, wherein the links and the end effector are spaced from one another along the direction of the axes such that the links can be moved orthogonally to the first direction over the static structure without obstruction from the static structure.~~

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17. A robotic arm mechanism as set forth in claim 16, wherein the elbow motor is connected to drive rotation in a respective one of the linkages and the shoulder motor is connected to drive rotation in a respective other of the linkages.

18. A robotic arm mechanism as set forth in claim 15, wherein the yaw motor is mounted to the relatively static structure generally along a respective one of the shoulder axes and the shoulder motor is mounted to the relatively static structure generally along the same shoulder axis, the mechanism further including belt and pulley means for transmitting rotational motion from the yaw motor to the distal axis, the elbow motor being mounted to a respective other of the shoulder axes, the mechanism further including belt and pulley means for transmitting rotational motion from the elbow motor to the elbow axis.

19. A robotic arm mechanism as set forth in claim 15, wherein the end effector has a plurality of hand portions each of which is capable of manipulating a workpiece.

20. A robotic arm mechanism as set forth in claim 19, wherein the links and the end effector are spaced from one another along the direction of the axes such that the links can be moved orthogonally to the first direction over the static structure without obstruction from the static structure.

21. A robotic arm mechanism as set forth in claim 20, wherein the elbow motor is connected to drive rotation in a respective one of the linkages and the shoulder motor is connected to drive rotation in a respective other of the linkages and the shoulder motor is connected to drive rotation in a

respective other of the linkages.

22. A robotic arm mechanism as set forth in claim 19, wherein the yaw motor is mounted to the relatively static structure generally along a respective one of the shoulder axes and the shoulder motor is mounted to the relatively static structure generally along the same shoulder axis, the mechanism further including belt and pulley means for transmitting rotational motion from the yaw motor to the distal axis, the elbow motor being mounted to a respective other of the shoulder axes, the mechanism further including belt and pulley means for transmitting rotational motion from the elbow motor to the elbow axis.

23. A robotic arm mechanism as set forth in claim 15, further including:

electronic controller means for controlling the end effector motor, the elbow motor and the shoulder motor;

sensor means for sensing the rotational positions of the end effector about the distal axis, the relative rotational positions of the proximal end portion of the respective one of the distal links and the distal end portion of the corresponding proximal link and the proximal end portion of the one of the proximal links relative to the static structure and for generating one or more electrical signals representative thereof;

means for communicating the one or more

electrical signals to the electronic computer means; the electronic computer means controlling the end effector motor, the elbow motor and the shoulder motor so as to position the end effector at a desired location.

24. A robotic arm mechanism as set forth in claim 23, wherein the links and the end effector are spaced from one another along the direction of the axes such that the links can be moved orthogonally to the first direction over the static structure without obstruction from the static structure.

25. A robotic arm mechanism as set forth in claim 24, wherein the elbow motor is connected to drive rotation in a respective one of the linkages and the shoulder motor is connected to drive rotation in a respective other of the linkages.

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26. A robotic arm mechanism as set forth in claim 23, wherein the yaw motor is mounted to the relatively static structure generally along a respective one of the shoulder axes and the shoulder motor is mounted to the relatively static structure generally along the same shoulder axis, the mechanism further including belt and pulley means for transmitting rotational motion from the yaw motor to the distal axis, the elbow motor being mounted to a respective other of the shoulder axes, the mechanism further including belt and pulley means for transmitting rotational motion from the elbow motor to the elbow axis.

27. A robotic arm mechanism as set forth in claim 23, wherein the end effector has a plurality of hand

portions each of which is capable of manipulating a workpiece.

28. A robotic arm mechanism as set forth in claim 27, wherein the links and the end effector are spaced from one another along the direction of the axes such that the links can be moved orthogonally to the first direction over the static structure without obstruction from the static structure.

29. A robotic arm mechanism as set forth in claim 28, wherein the elbow motor is connected to drive rotation in a respective one of the linkages and the shoulder motor is connected to drive rotation in a respective other of the linkages.

30. A robotic arm mechanism as set forth in claim 27, wherein the yaw motor is mounted to the relatively static structure generally along a respective one of the shoulder axes and the shoulder motor is mounted to the relatively static structure generally along the same shoulder axis, the mechanism further including belt and pulley means for transmitting rotational motion from the yaw motor to the distal axis, the elbow motor being mounted to a respective other of the shoulder axes, the mechanism further including belt and pulley means for transmitting rotational motion from the elbow motor to the elbow axis.

Sub. B5

31. In a robotic arm structure having θ-, R- and Z-motors for providing θ-, R- and Z-motions about a primary axis, the arm structure having an end effector portion thereof pivotally mounted for rotation about an end effector axis which is parallel to the primary axis, the arm structure being controlled by electronic

computer means controlling the θ-, R- and Z- motors and thereby the corresponding motions, sensor means for sensing the R, θ- and Z- motions and for creating electronic signals representative thereof and signal transmission means for delivering the electronic signals to the computer means, the improvement comprising:

means for providing yaw (Y) and roll (E) motion of the end effector;

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workpiece orientation determining means for determining the orientation of a workpiece which is to be picked up by the end effector and for creating an error electronic signal representative thereof;

means for transmitting the error signal to the computer means;

wherein the computer means includes means for computing corrections to be applied to the R, θ, Z, Y and E motions such that the workpiece can be picked up and transported by the end effector in a desired orientation.

32. A workpiece processing system which includes a conveyor belt which transports cassettes loaded with workpieces along a path such that the cassettes are not all radially accessible to the end effector in combination with the arm structure of claim 31.

33. A plurality of arm structures in accordance with claim 31, each having one or more work stations within its reach, the arm structures being position

sufficiently close together such that after a workpiece has been transported to one of the work stations within reach of a first of the arms and processed, it is then transported by the first of the arms to a transfer station which is also within the reach of the second of the arms for processing at work stations within the reach of the second arm.

34. A sensor array located in a position such that a workpiece being transported by an arm as set forth in claim 31 passes over the sensor array whereat any deviation in alignment of the workpiece, if present, is determined and an electronic error signal is generated and communicated to the electronic computer means which controls the arm to make the appropriate R-, θ-, Z- Y- and E- corrections to properly align the workpiece.

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35. In a robotic arm structure having θ-, R- and Z-motors for providing θ-, R- and Z-motions about a primary axis, the arm structure having an end effector portion thereof pivotally mounted for rotation about an end effector axis which is parallel to the primary axis, the arm structure being controlled by electronic computer means controlling the θ-, R- and Z- motors and thereby the corresponding motions, sensor means for sensing the R, θ- and Z- motions and for creating electronic signals representative thereof and signal transmission means for delivering the electronic signals to the computer means, the improvement comprising:

an elevator moveable along the Z axis, the robotic arm structure being supported by the elevator;

means for controllably tilting the elevator about any axis lying in a plane orthogonal to the Z axis;

means for providing yaw (Y), roll (E) and/or pitch (J) motion of the end effector;

workpiece orientation determining means for determining the orientation of a workpiece which is to be picked up by the end effector and for creating an error electronic signal representative thereof;

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means for transmitting the error signal to the computer means;

wherein the computer means includes means for computing corrections to be applied to control the tilting of the elevator, to the R, θ and Z motions and to one or more of the Y, E and/or J motions such that the workpiece can be picked up and transported by the end effector in a desired orientation.

36. A workpiece processing system which includes a conveyor belt which transports cassettes loaded with workpieces along a path such that the cassettes are not all radially accessible to the end effector in combination with the arm structure of claim 35.

37. A plurality of arm structures in accordance with claim 35, each having one or more work stations within its reach, the arm structures being position sufficiently close together such that after a workpiece has been transported to one of the work stations within

reach of a first of the arms and processed, it is then transported by the first of the arms to a transfer station which is also within the reach of the second of the arms for processing at work stations within the reach of the second arm.

38. A sensor array located in a position such that a workpiece being transported by an arm as set forth in claim 35 passes over the sensor array whereat any deviation in alignment of the workpiece, if present, is determined and an electronic error signal is generated and communicated to the electronic computer means which controls the arm to make the appropriate R-, θ-, Z-, Y- elevator tilting corrections to properly align the workpiece.

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39. In a robotic arm structure having θ-, R- and Z-motors for providing θ-, R- and Z-motions about a primary axis, the arm structure having an end effector portion thereof pivotally mounted for rotation about an end effector axis which is parallel to the primary axis, the arm structure being controlled by electronic computer means controlling the θ-, R- and Z- motors and thereby the corresponding motions, sensor means for sensing the R, θ- and Z- motions and for creating electronic signals representative thereof and signal transmission means for delivering the electronic signals to the computer means, the improvement enabling picking up and transporting workpieces in cassettes located in a planar region generally parallel to the Z axis, comprising:

means for providing yaw (Y) and pitch (J) motion of the end effector;

workpiece orientation determining means for determining the orientation of a workpiece which is to be picked up by the end effector and for creating an electronic signal representative thereof;

Sub. B7 Cont'd

means for transmitting the signal to the computer means;

wherein the computer means includes means for computing corrections to be applied to control the R, θ, Z, Y and J motions such that the workpiece can be picked up and transported by the end effector in a desired orientation.

40. A workpiece processing system which includes a conveyor belt which transports cassettes loaded with workpieces along a path in a planar region parallel to the Z axis such that the cassettes are not all radially accessible to the end effector, in combination with the arm structure of claim 39.

41. A plurality of arm structures in accordance with claim 39, each having one or more work stations within its reach, the arm structures being position sufficiently close together such that after a workpiece has been transported to one of the work stations within reach of a first of the arms and processed, it is then transported by the first of the arms to a transfer station which is also within the reach of the second of the arms for processing at work stations within the reach of the second arm.

42. A sensor array located in a position such that a workpiece being transported by an arm as set

forth in claim 39 passes over the sensor array whereat any deviation in alignment of the workpiece, if present, is determined and an electronic error signal is generated and communicated to the electronic computer means which controls the arm to make the appropriate R-, θ-, Z-, Y- and J- corrections to properly align the workpiece.

43. A method of processing workpieces to produce a product, comprising:

positioning a plurality of generally parallel workpieces in one or more cassettes, the cassettes being located within the scope of action of a robotic arm capable of R, θ, Z and Y and/or E and/or J motions, the cassettes having axes which are not coplanar with a primary axis of the robotic arm;

selectively independently rotating the end effector about a Y axis and/or a roll axis and/or a pitch axis;

monitoring the R, θ and Z positions of the arm and the Y and/or E and/or J positions of a wrist portion of the arm;

controlling the R, θ and Z positions of the arm and one or more of the Y and/or E and/or J positions of the wrist portion of the arm;

measuring the alignments of each workpiece as it is to be picked up by the arm;

controlling the arm so that each workpiece is

picked up and delivered in proper alignment for processing;

processing the workpieces to produce the product; and

recovering the product.

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